appear to be in "critical natural stability" (Hough and Fleming, 1974), and areas of between 10- and 20-percent slope are susceptible to sliding if improperly graded.

Merritt (1975) has prepared a similar map for the Hamilton County Regional Planning Commission for the unincorporated areas of Hamilton County. In that study, he elected to consider slopes in the Kope Formation inclined at 15 percent (8.5°) or more to be in a potentially unstable state. His model for landslide susceptibility also considers presence or absence of vegetation and Fairmount soil as stability factors. The Fairmount soil as classified and mapped by the U.S. Department of Agriculture, Soil Conservation Service, appears to include the colluvial soils developed by weathering of the shales.

## Generalized nature and distribution of glacial deposits

Landslides that occur in glacial deposits in the Greater Cincinnati area are not so readily predictable in terms of location and potential hazard as those associated with the Kope Formation because the distribution and nature of the glacial deposits are less predictable.

Southwestern Ohio was invaded by at least three continental glaciers that caused profound drainage changes and deposited a variety of materials in the valleys, along the hillsides, and on the upland surface. The distribution of the various materials is directly related to the sequence of glacial events and their effects. The following discussion, which is taken largely from Durrell (1961a, b) and Teller (1970, 1973), summarizes this history for the Cincinnati region.

Prior to the first ice advance in pre-Illinoian time, drainage was developed on a surface with 100 to 200 feet (30-60 m) of relief between upland divides at elevation 950 feet (290 m) MSL and drainageways. This drainage system, called the Teays system, flowed northward. The first ice advance into the Cincinnati area (called Kansan(?) or pre-Illinoian by different authors) caused ponding of the north-flowing streams, resulting in deposition of laminated clays in the lakes and initiation of major drainage changes. Erosional remnants of the clays are exposed near Clary-ville in Campbell County, Kentucky (fig. 1), and in some upland areas of Hamilton County, Ohio (Ettensohn, 1970; Teller, 1970). After retreat of the ice, the new river and many of its tributaries were cut several hundred

feet below the Old Teays valleys. The new river, called the Deep Stage drainage system, established the modern course of the Ohio River except in the vicinity of Cincinnati (fig. 6). Here the river flowed northward up the present valley of the Little Miami River, westward through Norwood in what is now called the Norwood Trough, northward again in the present Mill Creek valley into Butler County near Hamilton, Ohio, and then southwestward in a large valley now occupied by Miami River and Whitewater River drainage (fig. 1). The major river in Deep Stage time joined the modern course of the Ohio River near Lawrenceburg, Indiana (fig. 1). Once established, this river was entrenched 450 feet (137 m) below the Teays-age valley levels, or about 100 feet (30 m) below the present Ohio River flood plain.

The next ice advance, the Illinoian, blocked the Deep Stage drainage and created a large lake upstream, that is south and east, from Hamilton, Ohio. Lake clays and silts were deposited in the lake up to about elevation 600 feet (180 m) MSL. The ponding was of sufficient duration that the long, winding lake rose in height until it overtopped a divide about 3 miles (5 km) west of downtown Cincinnati near Anderson's Ferry (fig. 1). This final diversion produced the modern channel of the Ohio River. The ice advanced over the lake to about the present position of the Ohio River, capping the lake clays and silts with a layer of till. Following retreat of the Illinoian glacier, much of the till and lake clay from the valleys that were upstream from the glacial dam was eroded, leaving terraces of these materials as remnants. These terrace levels are at about elevation 650 feet (200 m) along the Mill Creek valley.

The last ice advance, the Wisconsin, did not extend as far south as previous advances, so the drainage modifications were minimal. Melt water transported large amounts of sand and gravel into the drainageways, which buried the Illinoian deposits at lower elevations in the valleys. Since Wisconsin time these deposits of sand and gravel have been dissected into matched and unmatched terraces extending up to 540 feet (160 m) MSL. Figure 7 is a generalized cross section across the Mill Creek valley showing the dissected upland capped by Illinoian Till, the dissected Illinoian terraces capped by Illinoian Till, the Wisconsin terrace level, and the flood plain of Mill Creek.

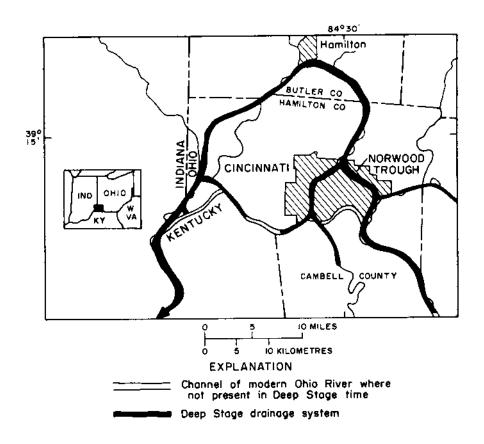


Figure 6.--Course of the Deep Stage drainage through Cincinnati. (From Teller, 1973.)

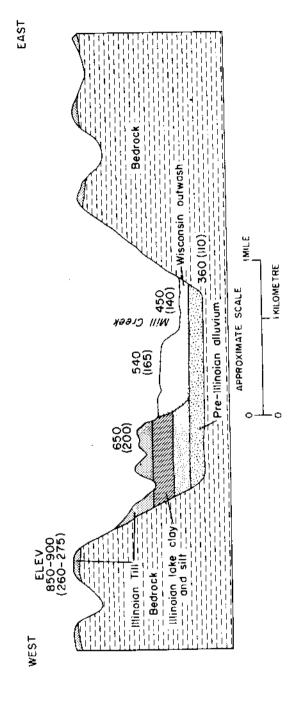


Figure 7.--Sketch of cross section of Mill Creek Valley showing distribution of glacial deposits. (Modified from Durrell, 1961b.)

## Stability problems associated with the glacial deposits

Landslide problems in glacial materials are associated with the lake clays and silts and with the Illinoian Till.

Older lake clays deposited during the ponding of the Teays-age streams generally are in sparsely populated areas, and experience with excavations and fills in these materials is limited. Where they have been disturbed, principally around Claryville, Kentucky, the clays are somewhat unstable, but landslides are neither large nor widespread. Klusman (1973) collected several samples of the clays from that area and performed index tests on them. His results are shown in table 2, combined with similar data for glacial till.

The laminated silts and clays which were deposited as a result of the blockage of Deep Stage drainage by Illinoian ice are unstable in slopes. Furthermore, the outcrop elevations of these clays overlap with the Kope Formation and the clays commonly overlie the colluvium on the Kope Formation. A major landslide occurred in 1958 in Mill Creek valley at the Courter Technical High School (location 1, fig. 1), where excavation at the foot of the slope for a freeway triggered a failure several hundred feet long. The failure surface was both in colluvial materials on the Kope Formation and in the silts and clays (R. H. Durrell, oral commun., 1972). Nearby, the clays have failed along the east side of Interstate Highway 75, between Mitchell and Ludlow Avenues in Cincinnati. Here the failure surfaces are thought to be entirely in lake clays or in lake clays capped by Illinoian Till.

Because of the complex history of the lake clays, their distribution is not readily predictable. They occur in dissected terraces in Mt. Washington on the east edge of Cincinnati, in Mt. Adams near downtown Cincinnati, and along Mill Creek valley. Ponding extended to tributaries of the Principal river in Deep Stage time, and these smaller valleys were subsequently covered with till, masking their location. At present not enough is known about the properties, distribution, or modes of failure to generalize as to their behavior patterns. Physical property data from one site of a buried tributary in northwestern Cincinnati are shown in table 2.

The glacial till of Illinoian age is widespread on the dissected upland and caps the upper-level terraces. No landslides have been observed in natural slopes in this material, but landslides in man-modified cuts and

Table 2.--Summary of physical property data for some glacial deposits

[Sources of data are listed in "Acknowledgments"]

	Liquid limit (% H <sub>2</sub> O)	Plastic limit (% H <sub>2</sub> O)	Moisture content (percent)	Dry density (lb/ft³)	Unconfined compressive strength (t/ft²)	Clay (% <2µ)
		I	llinoian Til	1		<u></u>
Northwestern Cincinnati	38 (7)*	20 (7)	19 (7)	105.8 (8)	2.2 (4)	<b>-</b>
North-central Cincinnati	28 (4)	16 (4)	17 (4)	118.0 (4)	4.5 (4)	
		Teay	s-age lake	clays		
Claryville, Kentucky	54 (8)	28 (8)				82 (7)
		Deep S	tage-age la	ke clays		<u></u>
Northwestern Cincinnati	67 (5)	31 (5)	35 (10)	94.8 (2)	0.7 (2)	

\*Number in parentheses is number of determinations averaged to obtain indicated property.

fills are common. Of the 49 slides described by Yahne (1974) in the g-square-mile (23-km²) area on hill slopes and uplands about 1 mile (1.6 km) north of downtown Cincinnati, 16 occurred in glacial till as compared to 12 in colluvium on the Kope Formation. Another 20 landslides could not be ascribed to any particular formation, because they were failure of transported fills. However, the preponderance of this fill material was glacial till, and most of the fills were placed on glacial till.

These landslides have the morphology of a typical slump and are usually each a single, well-defined unit. The failure surface appears to be curved throughout, although not necessarily circular. The failure surface in some slides that are in fill appears to follow the contact between the fill and the underlying, undisturbed material.

Yahne (1974) could find no strong correlation between presence or absence of vegetation and distribution of slope failures. Only 4 of the 49 failed slopes faced southward, and more than half of them faced northward or northeastward. This probably reflects a tendency for north-facing slopes to be more moist and therefore not as strong as their south-facing counterparts.

The slope angles of till before sliding ranged from 23° to 38° (42-78 percent) for 13 of the 14 slopes; the average slope angle before sliding was 29° (55 percent). The other slope failed to such an extent that the original slope angle could not be determined. Table 2 summarizes some of the physical properties of the till.

Slope failures in Illinoian Till are usually associated with a small grading operation such as placement of material from a basement excavation into a backyard for fill or excavation of a small cut for access. In many of these instances the grading seemingly was performed without benefit of a stability analysis. Large earth-moving projects in glacial till rarely result in landsliding, especially when they are preceded by adequate analysis and control of construction.

## Summary

Landslide problems are common and long standing in the Greater Cincinnati area. The preponderance of landslides occurs in colluvium derived from slaking of shales in the Kope Formation, in laminated clays and silts that were deposited in lakes in ancient valleys formed by blockage of the rivers by glacial ice, and in glacial till. The distribution of the Kope Formation is fairly well known and the location and nature of problems can be anticipated, but much more work is necessary to determine the distribution of glacial materials and the processes leading to their instability.

## Acknowledgments

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